

STINFO COPY



AFRL-HE-WP-TR-2007-0063

**Head Tracker Evaluation Utilizing the
Dynamic Tracker Test Fixture**

**Judson La Moure Shattuck III
Vincent M. Parisi
Arryn J. Smerdon**

**Air Force Research Laboratory
Human Effectiveness Directorate
Wright-Patterson AFB OH 45433-7022**

March 2007

Final Report for the period June 2004 to March 2007

**Approved for public release;
distribution is unlimited.**

**Air Force Research Laboratory
Human Effectiveness Directorate
Warfighter Interface Division
Battlespace Visualization Branch
Wright-Patterson AFB OH 45433**

NOTICE AND SIGNATURE PAGE

Using Government drawings, specifications, or other data included in this document for any purpose other than Government procurement does not in any way obligate the U.S. Government. The fact that the Government formulated or supplied the drawings, specifications, or other data does not license the holder or any other person or corporation; or convey any rights or permission to manufacture, use, or sell any patented invention that may relate to them.

This report was cleared for public release by the Air Force Research Laboratory Wright Site Public Affairs Office and is available to the general public, including foreign nationals. Copies may be obtained from the Defense Technical Information Center (DTIC) (<http://www.dtic.mil>).

TECHNICAL REVIEW AND APPROVAL

AFRL-HE-WP-TR-2007-0063

**THIS TECHNICAL REPORT HAS BEEN REVIEWED AND IS APPROVED FOR
PUBLICATION.**

FOR THE DIRECTOR

//signed//

DANIEL G. GODDARD

Chief, Warfighter Interface Division

Air Force Research Laboratory

This report is published in the interest of scientific and technical information exchange, and its publication does not constitute the Government's approval or disapproval of its ideas or findings.

REPORT DOCUMENTATION PAGE				Form Approved OMB No. 0704-0188		
<small>Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Washington Headquarters Service, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington, DC 20503.</small>						
PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.						
1. REPORT DATE (DD-MM-YYYY) 1 Mar 2007		2. REPORT TYPE Final		3. DATES COVERED (From - To) June 2004 to March 2007		
4. TITLE AND SUBTITLE Head Tracker Evaluation Utilizing the Dynamic Tracker Test Fixture				5a. CONTRACT NUMBER In-House		
				5b. GRANT NUMBER		
				5c. PROGRAM ELEMENT NUMBER 63231F		
6. AUTHOR(S) Judson La Moure Shattuck III Vincent M. Parisi Arryn J. Smerdon				5d. PROJECT NUMBER 2830		
				5e. TASK NUMBER 02		
				5f. WORK UNIT NUMBER 28		
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)				8. PERFORMING ORGANIZATION REPORT NUMBER		
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Air Force Materiel Command Air Force Research Laboratory Human Effectiveness Directorate Warfighter Interface Division Battlespace Visualization Branch Wright-Patterson AFB OH 45433-7022				10. SPONSOR/MONITOR'S ACRONYM(S) AFRL/HECV		
				11. SPONSORING/MONITORING AGENCY REPORT NUMBER AFRL-HE-WP-TR-2007-0063		
12. DISTRIBUTION AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.						
13. SUPPLEMENTARY NOTES AFRL/PA Cleared 2/26/07 AFRL/WS-07-0390.						
14. ABSTRACT In military aviation, head tracker technologies have become increasingly important to track the pilot's head position and orientation, allowing the user to quickly interact with the operational environment ¹ . This technology allows the pilot to quickly acquire items of interest and see Fighter Data Link type information. Acquiring the target on a helmet-mounted tracker/display which can automatically slew a weapon's seeker is far more efficient than having to point at the target with the nose of the aircraft as previously required for the heads-up display type of target acquisition. The United States Air Force has used and evaluated a variety of helmet-mounted trackers for incorporation into their high performance aircrafts. The Dynamic Tracker Test Fixture (DTTF) was designed by the Helmet-Mounted Sensory Technology laboratory to accurately measure rotation in one plane both static and dynamic conditions for the purpose of evaluating the accuracy of head trackers, including magnetic, inertial, and optical trackers. This paper describes the design, construction, capabilities, limitations, and performance of the DTTF.						
Azimuth Measurement, Head Tracker, Helmet-Mounted Trackers, Dynamic Measurement, Static Measurement						
16. SECURITY CLASSIFICATION OF: Unclassified			17. LIMITATION OF ABSTRACT SAR	18. NUMBER OF PAGES 25	19a. NAME OF RESPONSIBLE PERSON Douglas Franck	
a. REPORT U	b. ABSTRACT U	c. THIS PAGE U			19b. TELEPHONE NUMBER (Include area code)	

This page blank intentionally.

TABLE OF CONTENTS

List of Figures.....	iv
Acknowledgements.....	v
1.0 Summary.....	1
2.0 Introduction.....	2
3.0 Methods, Assumptions, and Procedures.....	4
3.1 Component Description.....	4
3.2 Spool.....	4
3.3 Spindle.....	5
3.4 Carriage.....	5
3.5 Encoder.....	5
3.6 Leveling Feet.....	7
3.7 Mounting Bracket	8
3.8 Data Acquisition.....	8
3.9 System Operational Description.....	9
3.10 Static Operation.....	10
3.11 Dynamic Operation.....	10
4.0 Results and Discussions.....	12
4.1 Spool and Spindle Characterization.....	13
4.2 Considerations before Data Collection.....	13
4.3 Head Tracker Velocity Data.....	14
4.4 Head Tracker Dynamic Azimuth Data.....	15
5.0 Conclusions.....	17
6.0 References.....	18
7.0 List of Symbols, Abbreviations, and Acronyms.....	19

LIST OF FIGURES

FIGURE 1: Dynamic Tracker Test Fixture (Front View)	6
FIGURE 2: Non-ferrous Mounting Bracket.....	7
FIGURE 3: Axis of Motion.....	10
FIGURE 4: Dynamic Rotation of the DTTF.....	11
FIGURE 5: Elevation and Roll Verse Position for the DTTF.....	12
FIGURE 6: Head Tracker Velocity Verse Position.....	15
FIGURE 7: Head Tracker Data, Tracker Azimuth Minus Encoder Azimuth for the DTTF.....	16

ACKNOWLEDGEMENTS

The authors express their appreciation to Mr. Mike Sedillo for his support in setting up these tests and for meticulous data collection. We are also thankful for the software support from Mr. Eric Heft.

(THIS PAGE INTENTIONALLY BLANK)

1.0 SUMMARY

Helmet-mounted trackers and displays for presenting information to pilots and slewing weapons are being incorporated into aircraft. There are several different types of trackers from magnetic, optical, acoustic, and inertial. Questions arise in how accurate do trackers need be and how do you measure these systems. These concerns led to the development of the Dynamic Tracker Test Fixture (DTTF) to accurately measure rotation in one plane both static and dynamic conditions. This paper will describe the DTTF development and the characterization of the device.

2.0 INTRODUCTION

Head tracker technologies in military aviation make the Fighter Data Link type information more useful for the pilot. Acquiring a target with a helmet-mounted display equipped with Tracker-Assisted Weapons-Slewing is far more efficient than pointing the nose of the aircraft at the target, as was previously required for a heads-up display (HUD) type of target acquisition.

The three primary head tracker technologies available are magnetic trackers, inertial trackers, and optical trackers. Each head tracker technology has its own method of determining the pilot's head position within the cockpit of the aircraft. Magnetic trackers are generally small and light weight. To determine position, a magnetic receiver senses the strength and orientation of a tri-axial field generated by a magnetic transmitter. In a perfect environment the transmitted magnetic field would form a uniform field about each of the transmitter's axes. However their accuracy can be affected by distortions caused by other magnetic fields or ferrous components within the cockpit. These distortions can usually be accommodated by "mapping" the area of the cockpit to establish the magnetic fields present². This "mapping" discovers the resulting magnetic field including, all distorting component affects. Any change within the cockpit or on the helmet can change the distortions, invalidate the map, and require remapping. Inertial trackers do not require mapping, can be very responsive and cover a large area in the cockpit but require constant motion in order to accommodate drifting of the inertial sensors. They may use a secondary system that updates the inertial system--often referred to as a hybrid system. Optical head trackers (OHT) are immune to magnetic field distortions and have no requirement for constant motion, but have their own

limitations including daylight/night vision goggle (NVG) compatibility and may require numerous emitters and/or receivers to cover a large head motion box with a wide field of regard.

The United States Air Force (USAF) and the Battle Space Visualization Branch of the Warfighter Interface Division (AFRL/HECV) has used and evaluated a variety of helmet-mounted trackers for potential incorporation into their various aircraft. In order to understand the performance of a particular tracking system a method to quickly and accurately evaluate them in both static and dynamic conditions is necessary. The evaluation method must not interfere with the head tracker's normal operation. For example, the measurement device can not adversely affect the "normal" magnetic field for a magnetic tracker or cause interfering emissions for optical trackers.

This paper describes the Dynamic Tracker Test Fixture (DTTF) which accurately measures head tracker static and dynamic performance, one plane at a time, without interfering with the normal operation of head trackers.

3.0 METHODS, ASSUMPTIONS, AND PROCEDURES

3.1 Component description

The Dynamic Tracker Test Fixture³ (DTTF) is shown in Figure 1 with all of its major components, the most important being the spool, spindle (not seen in the picture), carriage (not seen in the picture), encoder, leveling feet, the data acquisition system and customized software (not pictured). It is constructed of non-ferrous components, except for the encoder, which minimizes magnetic field interference for use in evaluating magnetic head trackers. An additional component of the DTTF is a non-ferrous mounting bracket which can be mounted atop the spool as shown in Figure 2. Most of the principle components of the DTTF are fabricated from polycarbonate, while the remaining components are fabricated from aluminum.

3.2 Spool

The spool is pressed onto the spindle through a precision cut bore and held in place with a set screw. The other end of the spindle is connected to the encoder, thus mechanically connecting the two components and transferring spool motion to the encoder with a ratio of 1:1.

The spool is grooved about the outer perimeter which serves as a guide for a string that tethers a weight used during dynamic data collection. The top of the spool is drilled every 1" on center with 1/4"-20 threads, identical to standard optical tables. This allows mounting of standard optical hardware and custom fixtures.

3.3 Spindle

The spindle is precision machined from a stock of aluminum and is hard anodized to minimize any wobble or bending which might occur if it was fabricated from polycarbonate. The spindle, which rides in a precision bore inside the carriage, transfers spool motion to the encoder. The spindle has a flat notch or “D” shape where it contacts the spool so a set screw can securely fasten the two components together.

3.4 Carriage

The carriage serves two primary functions. First, it mechanically supports the spool with a mating shouldered surface and is precision bored to help align the spindle and transfer rotational movement from the spool to the encoder. The precision boring minimizes any wobble motion of the spindle and accordingly, the spool itself. Second, it provides a means to move and stop the spool at any combination of 15° increments about its 360° rotation if the set screws are spun in. The set screws are a position aid; they are not intended as an exact reference point. With no set screws in place the spool is free to rotate.

3.5 Encoder

The encoder is a metrology-grade measurement device specifically designed for rotary tables with a resolution of 0.0001° (0.36 arc/sec) and an accuracy of ± 1.25 arc/sec. The encoder's position data output are two quadrature pulse streams with 3,600,000 counts per revolution, an index marker and out-of-tolerance marker. Under dynamic conditions, the encoder can accurately output data at a maximum rate of 1000 rev/min (RPM) or 104.7 rad/sec.

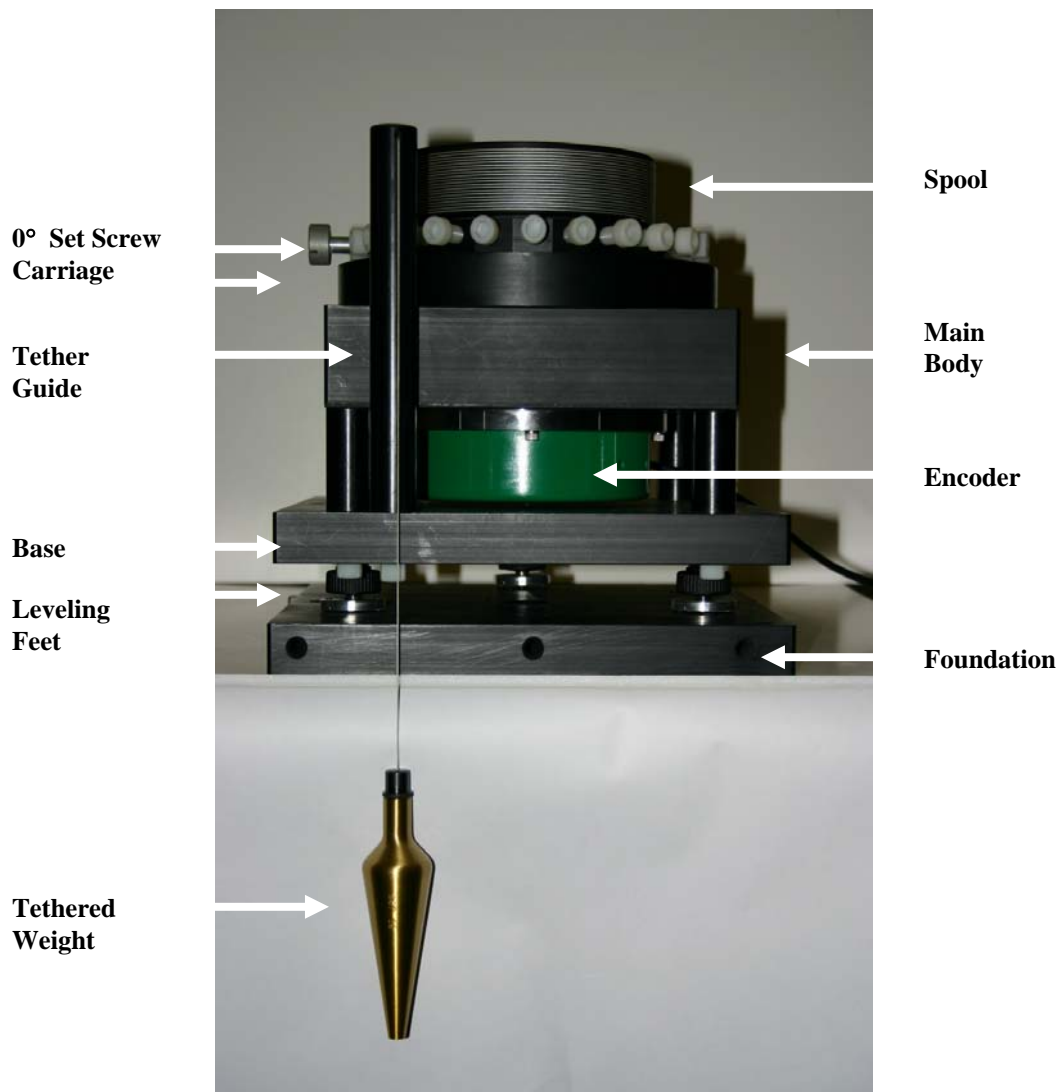


Figure1. Dynamic Tracker Test Fixture (Front View)

The index marker generates a high output signal once every revolution at the same physical location with respect to the encoder's internal shaft. This index can be used to identify the absolute beginning of a rotation (0 counts) or to determine an offset, by number of counts, from where an

absolute beginning is desired. Thus, the exact starting and ending position, within 0.0001° or 1/3,600,000 counts, can be found and repeated. The out-of-tolerance marker generates a low pulse indicating faulty encoder operation.

The encoder is mounted to the main body and connected to the spool through the spindle, as seen in Figure 1. A specialized shaft coupler is used to mount the spindle to the encoder, which protects the encoder, should the spindle be moved side-to-side and compensates for any spindle alignment or assembly anomalies.

3.6 Leveling feet

The base of the DTTF is supported by a set of three leveling feet, arranged in an equilateral triangle configuration. This is the identical configuration used in most precision surveying equipment.

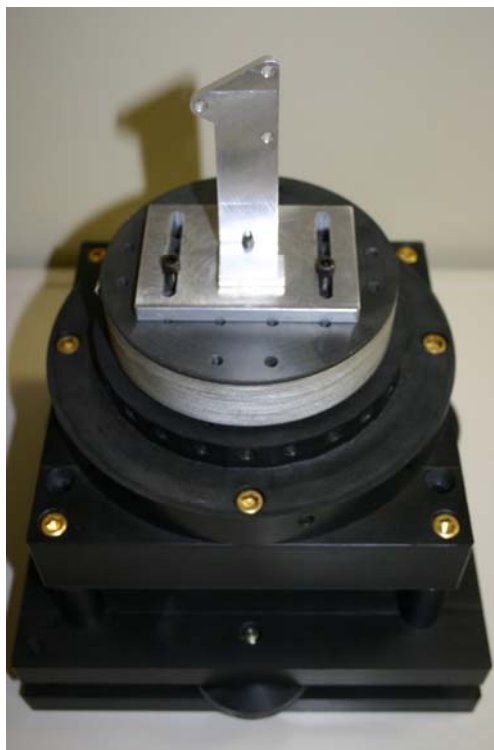


Figure 2. Non-ferrous mounting bracket

3.7 Mounting bracket

The mounting bracket shown in Figure 2 is one of several custom fabricated brackets designed to hold the appropriate moving piece of the tracker unit. The brackets are manufactured from nonferrous materials, such as aluminum, and designed to be mounted directly over the spindle when anchored to the spool.

To help prevent inducing elevation or roll errors caused by the torque of the spool/spindle assembly as it is rotated, the center of gravity of the bracket and transmitter combination must be positioned over the center of the spool and spindle. Thus, when the mounting bracket is designed, the center of gravity of the bracket and transmitter combination is determined and the appropriate counter weight included. For optimum accuracy, each tracker device requires a unique mounting bracket.

3.8 Data acquisition

Raw quadrature data are collected from the encoder with a PCI-4E interface card specifically designed for incremental encoders. Encoder data are processed using a 24-bit real time up/down counter with a count range from 0 to 16,777,215 and are stored at approximately 150,000 samples per second to a data array. Each sample consists of four 24-bit encoder position counters and a 33 MHz time stamp.

Using the PCI-4E driver software, position data are displayed as counts displaced from the index or counts displaced from an arbitrary user established position which is an offset amount from the index. This arbitrary position is established by the “Re-Set” function. Data can be collected by

manually reading the information from the display or by defining either a sampling rate, specific number of samples, or both, and recording the information to disk.

The software for each head tracking system is integrated into the PCI-4E driver software and modified to enhance automated data acquisition to minimize post processing requirements.

3.9 System operational description

The DTTF is a mechanical device used to measure rotation about the Z axis as defined and shown in Figure 3. The spool can rotate in either a clockwise (CW) or counter clockwise (CCW) direction; however, the tethered weight (see Figure 1) only allows assisted motion in the CCW direction. To use the DTTF in the evaluation of a head tracker system, the tracker component is mounted atop the spool with the appropriate mounting bracket. Although head tracking systems usually measure all three axes of motion (azimuth, elevation, and roll) the DTTF is only capable of measuring rotation about its vertical (Z) axis as defined in Figure 3.

To make measurements in other directions, the item under test must be mounted such that the desired axis of rotation is aligned with the DTTF's Z axis and suitable adjustments to the tracker's complimentary transmitter/receiver/sensor made. For inertial trackers this will be problematic since gravity would now be affecting the wrong axis.



Figure 3. Axis of Motion

3.10 Static operation

The spool can be rotated to one of the set screw locations or stopped at any desired position to make a measurement at a specific location. If the set screws are used as a general positioning locator, the tethered weight may be used to apply a constant force against them, allowing for quick placement in approximate positions at 15 degree increments. In either situation, the encoder, PCI-4E driver, and custom modified software accurately display the encoder position at all times. To collect positional data a software button is activated. Once all data collection is finished, another software button is activated and the data is written to an output file with time and date information.

3.11 Dynamic operation

For dynamic operation the tethered weight is used to apply a constant force in the CCW direction. With all set screws spun-out and the weight released the spool will accelerate, continuing to rotate until the tethered weight stops traveling and the spool coasts to a stop. The speed of the rotation can be adjusted with various weights. The PCI-4E driver software collects position and time stamp data. Figure 4 shows a sample of position data collected under dynamic conditions for four rotations of the spool. From left to right the accelerations are 4.659 rad/sec, 12.843 rad/sec, 15.932 rad/sec, and

18.026 rad/sec, respectively. The accelerations are increasing as frictional forces are overcome. Several runs were made in this test and the results compared favorably.

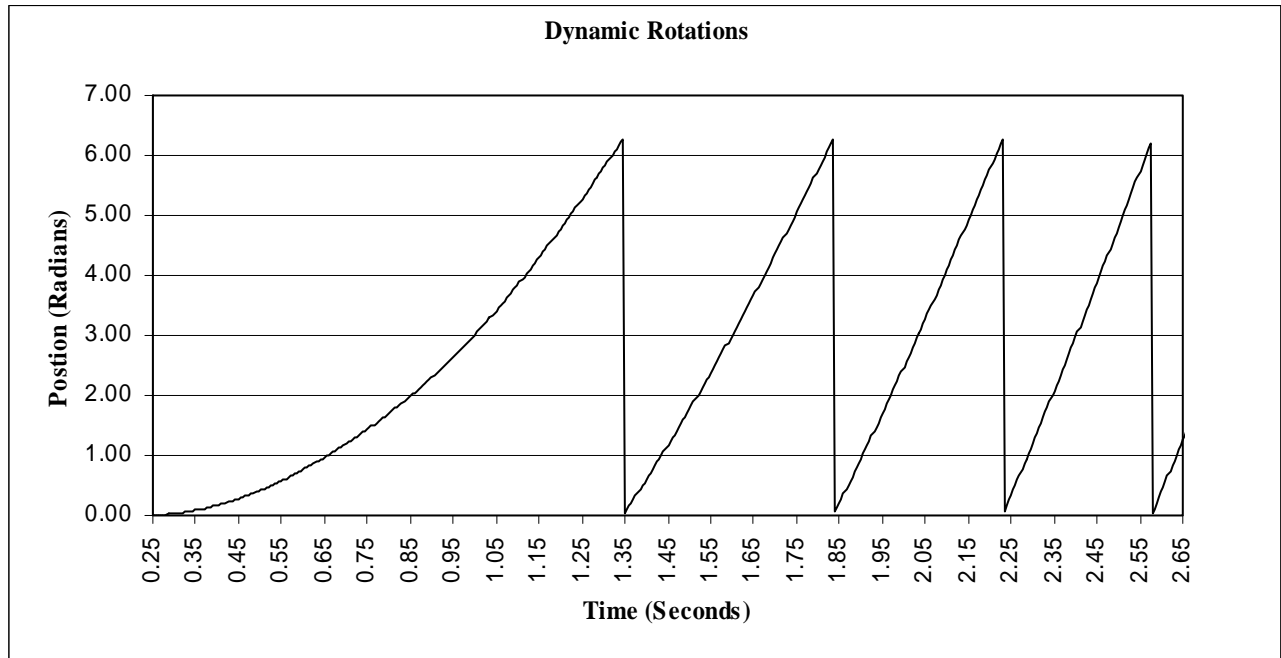


Figure 4. Dynamic Rotation of the DTTF

Before beginning dynamic data collection, sample rate and collection time are determined.

Typically data collection starts one or two seconds before the spool is set in motion and continues for several seconds after it is expected to stop, helping assure no loss of data. Under dynamic conditions the encoder can accurately output data at a maximum rate of 1000 rev/min (RPM) or 104.7 rad/sec.

4.0 RESULTS AND DISCUSSIONS

Under perfect conditions with a perfect system the DTTF would rotate solely in azimuth (about the Z axis). Because this system is imperfect it was characterized to determine cross coupling between the azimuth and the elevation and roll axes. The results of this characterization are presented here. The details of the characterization process are detailed in Shattuck, Parisi, and Smerdon's⁴ publication "Non-Contact Method for Characterization of a Rotational Table".

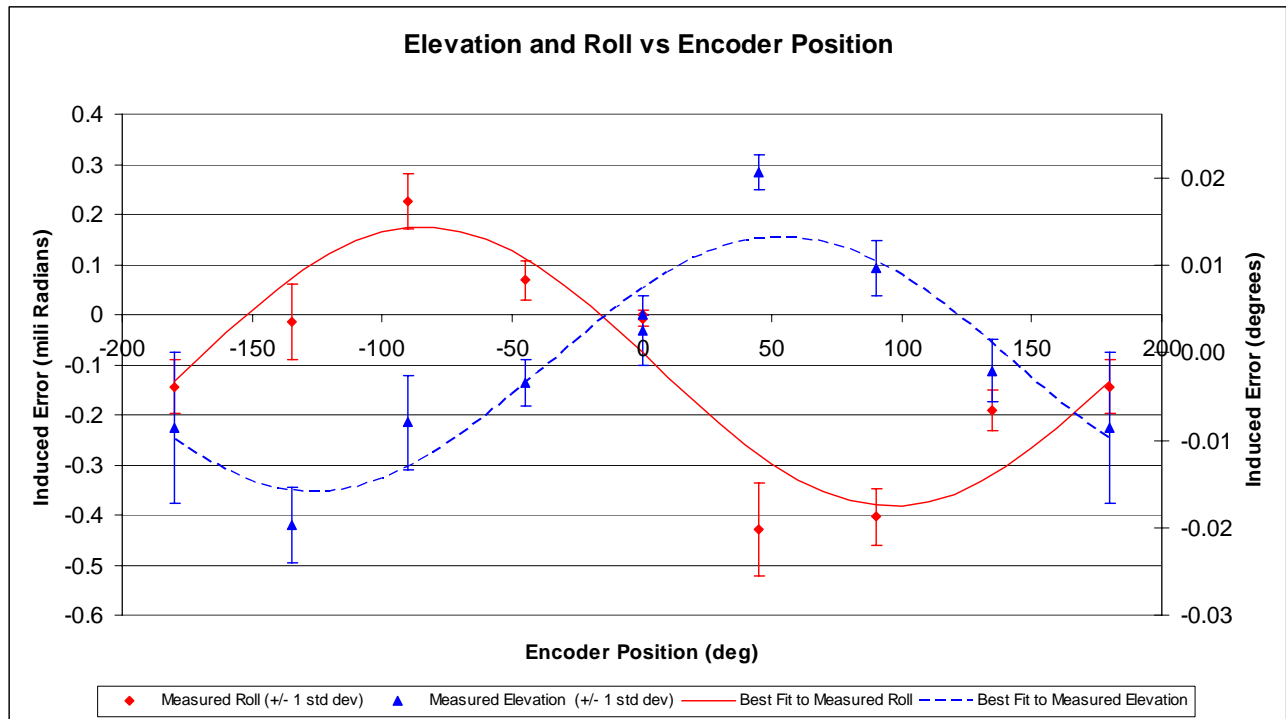


Figure 5. Elevation and Roll verse Position for the DTTF

(---- Elevation, — Roll)

4.1 Spool and spindle characterization

Figure 5 shows the cross coupling between azimuth and the elevation and roll axes. The measured data shown as data points with standard deviation bars suggest a sine wave pattern. This would be expected if the error is from a misalignment between the reference frames. Figure 5 also shows two sine wave curves which represent the best fit sine pattern for each data set. In any event, the “error” contribution is quite small with a max value of approximately ± 0.3 mrad. Additionally, the contribution of elevation and roll are similar in amplitude though opposite in phase.

This data was measured by reflecting a laser beam off the top center of the spindle and projecting the returned light onto a distant surface⁴. This data suggests that the spindle “wobbles” in the fixture. If the spindle/spool rotated purely around the Z axis, the reflected beam’s spot on the projected surface would remain stationary while a moving spot would indicate a rotation about the X and/or the Y axis. As a result of these measurements, we undertook an effort to re-manufacture the spindle and bearings in an attempt to reduce the “wobble” effect. The results of those improvements are not included in this paper.

4.2 Considerations before data collection

Before collecting data from a head tracker using the DTTF, a unique mounting bracket is required which places the center of gravity of the transmitter directly over the spindle as described in section 2.1.6 and shown in Figure 2. Any manufacturers’ set-up instructions are accomplished and the system is aligned. If dynamic data collection is desired, any cabling must be secured so it does not interfere with the head tracker’s operation as it rotates.

The desired velocity of rotation is determined and the appropriate weight selected as shown in Figure 1. Because the mass of the transmitter and mounting bracket will vary for each head tracker, especially between types of head trackers, a trial and error method is used for weight selection. After each test run, the velocity curve is plotted until the desired velocity curve is achieved.

Another set-up condition to consider is the number of consecutive rotations desired during a single run. If multiple rotations are desired, possible interference of cabling must be investigated. Finally, if the head tracker under test is not able to track a complete 360° rotation there may be a lag time before they reacquire and start retransmitting accurate position data. The manufactures specifications must be investigated before this type of testing begins.

4.3 Head tracker velocity data

The data in Figure 6 shows three individual velocity curves collected from a head tracker using the DTTF in conjunction with the head trackers software. All three runs were propelled by the identical weight and are tightly grouped together,

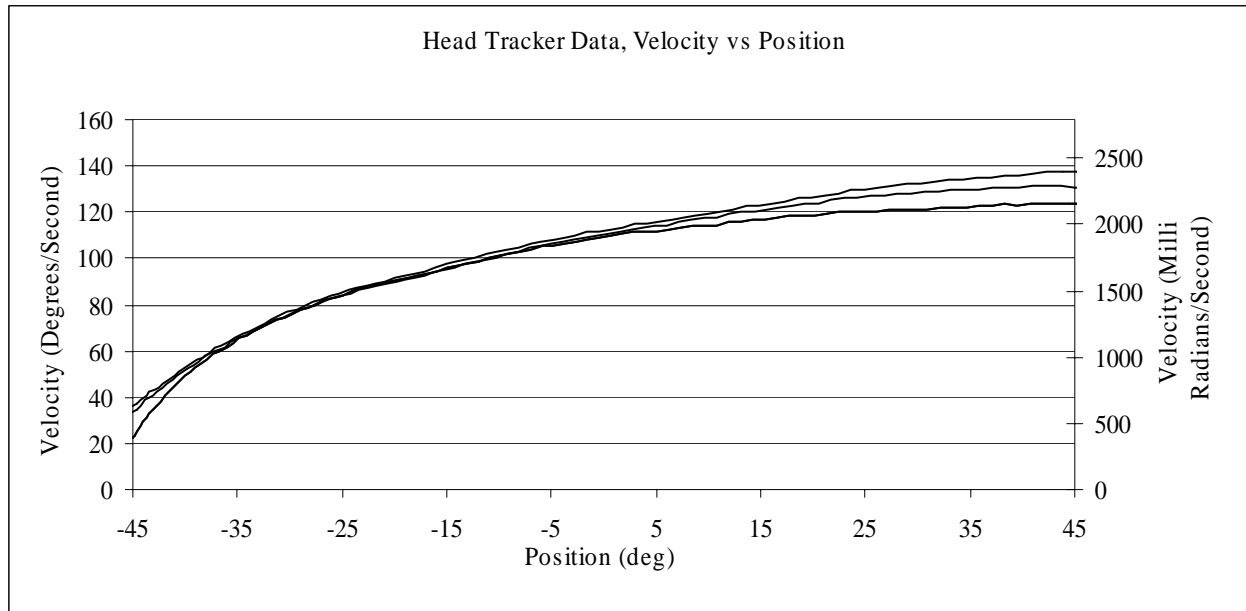


Figure 6. Head Tracker Velocity verse Position

indicating consistency between runs. The maximum velocity achieved is approximately 140 deg/sec (23.3 rev/min) or 2500 mrad/sec (2.5 rad/sec), which is under the head tracker's maximum velocity specification of 1000 rev/min and 104 rad/sec.

4.4 Head tracker dynamic azimuth data

Figure 7 shows a typical error plot of one tracker unit's azimuth output minus the encoder position during a dynamic data collection run. No attempt is made there to evaluate the tracker's performance, rather only to show a typical set of data that is normally collected.

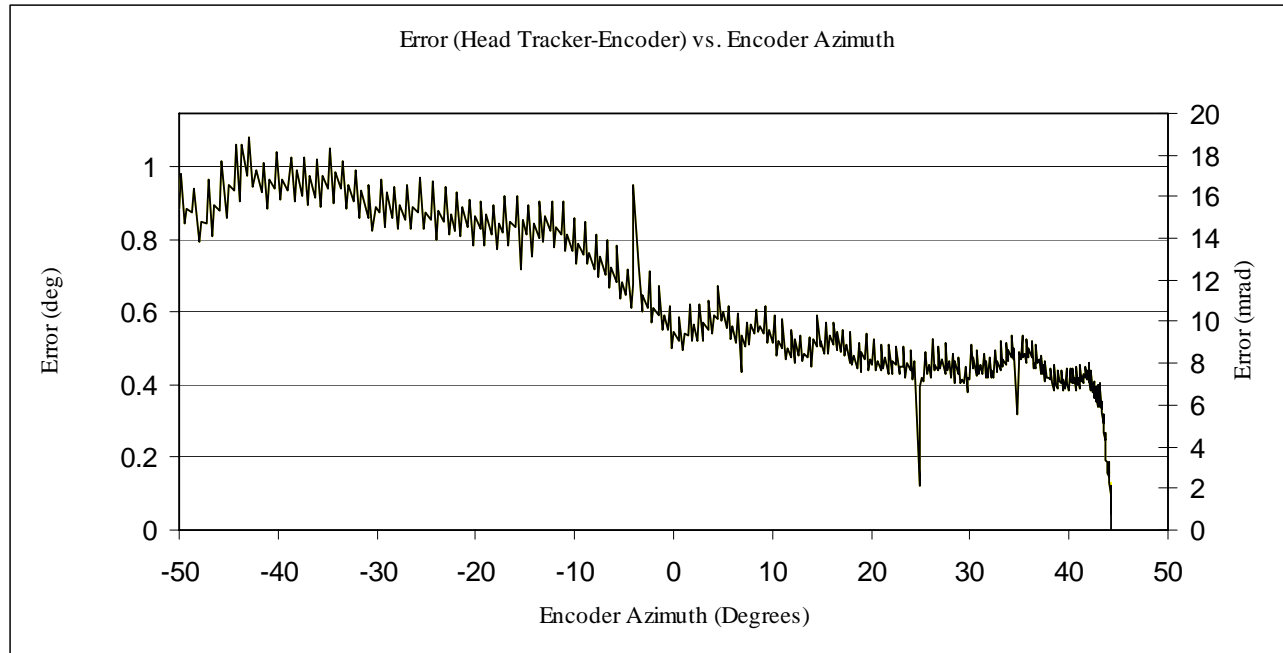


Figure 7. Head Tracker Data, Tracker Azimuth minus Encoder Azimuth for the DTTF

5.0 CONCLUSION

This paper describes the construction, characterization and use of the Dynamic Tracker Test Fixture in evaluating helmet-mounted trackers about the azimuth axis in a laboratory environment. The system can be used for very accurate static or dynamic measurements about this single axis.

Depending on the tracker technology being evaluated, it may be possible to evaluate a tracker's other axes (elevation and/or rotation) by rotating the tracker element on the fixture such that, as the fixture rotates in azimuth, the tracker rotates about one of these other axis. It is further noted that, even though the dynamic forcing function is not accurately controlled, the measurements taken during the dynamic process are very accurate. Thus, comparisons can be made from measurement run to run by matching up velocities and/or accelerations. Several runs may be necessary to completely evaluate a tracker system in its entire operational envelope.

The DTTF offers an effective and accurate method to evaluate magnetic, inertial and optical helmet-mounted tracker systems in both the static and dynamic environments without significantly affecting the trackers performance. The maximum error contribution is approximately +/- 0.3 mrad in both elevation and roll. For dynamic testing, the DTTF is capable of making accurate measurements up to 1000 rev/min (RPM) or 104.7 rad/sec.

6. REFERENCES

1. Kocian, Dean F. and Task, H. Lee, “Visually Coupled Systems Hardware and Human Interface,” in Woodrow Barfield and Thomas A. Furness III (eds.), Virtual Environments and Advanced Interface Design, Oxford University Press, 1995
2. J.B. Kuipers, “Characterization & Application of Quaternions for Enhanced Computer Processing Algorithms”, SBIR II Final Report (U), Report No. AL/CF-SR-1994-0014, Kuipers and Associates, 3085 Baker Park Drive, Southeast Grand Rapids MI 49508-1474
3. Shattuck III, Judson La Moure and Parisi, Vincent M., “Dynamic Tracker Test Fixture, Static and Dynamic Characterization of a Rotational Table Designed to Evaluate Azimuth Motion”, Helmet-and Head-Mounted Displays XI: Technologies and Applications, SPIE Vol 6224, April 2006
4. Shattuck III, Judson La Moure, Parisi, Vincent M, and Smerdon, Arryn J. “Non-Contact Method for Characterization of a Rotational Table”, Helmet-and Head-Mounted Displays XI: Technologies and Applications, SPIE, April 2007

7. LIST OF SYMBOLS, ABBREVIATIONS, AND ACRONYMS

CCW – Counter Clockwise

CW – Clockwise

Deg – Degrees

DTTF – Dynamic Tracker Test Fixture

HUD – Head-up Display

Min – Minute

Mrad – milliradian

NVG – Night Vision Goggle

OHT – Optical Head Trackers

Rad – Radian

Rev – Revolutions

RPM – Revolutions Per Minute

Sec – Second

USAF – United States Air Force